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*Atmospheric Infrared Sounder*

# Validation of Six Years of Mid-Topospheric AIRS CO<sub>2</sub>

Edward Olsen<sup>1</sup>, Moustafa Chahine<sup>1</sup>, Luke Chen<sup>1</sup>,  
Xun Jiang<sup>2</sup>, Thomas Pagano<sup>1</sup> and Yuk Yung<sup>3</sup>

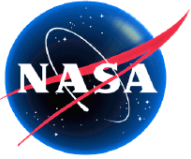
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<sup>3</sup> Division of Geological & Planetary Sciences, Caltech

NASA Sounding Science Meeting, May 4-7, 2009

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# Outline

## ✧ Validation

- ✧ AIRS Mid-Tropospheric CO<sub>2</sub> Averaging Kernels
- ✧ Aircraft profiles of CO<sub>2</sub> concentration  
→ Direct validation of satellite retrievals
- ✧ CONTRAIL CO<sub>2</sub> samples at altitudes 10.5 km to 12.5 km  
→ Validate amplitude, phase of seasonal variations  
and interannual trends as function of latitude
- ✧ TCCON daytime cloud-free column average CO<sub>2</sub>  
measurements  
→ Validate phase of seasonal variations and interannual  
trends; allows estimation of drawdown in PBL

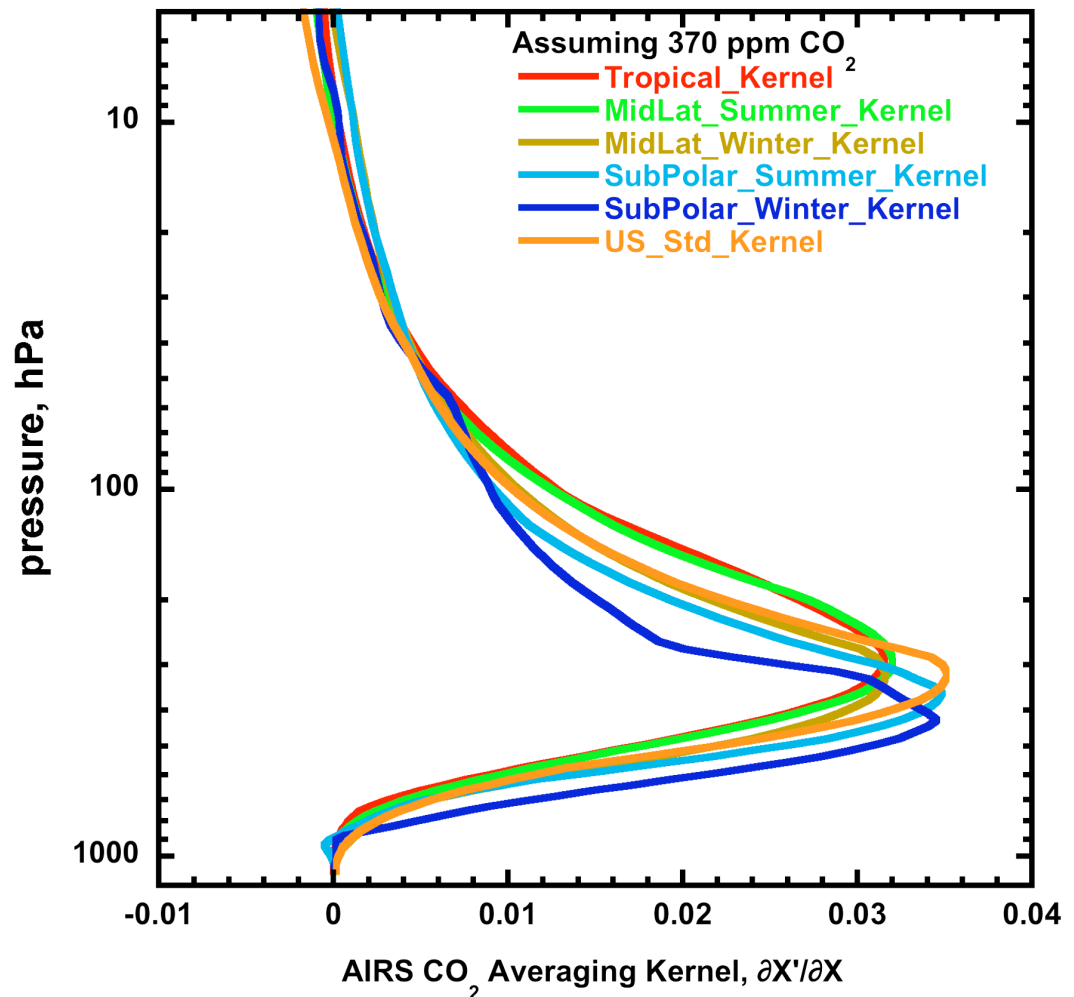
## ✧ Conclusions

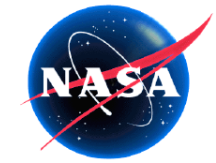
## ✧ An Encore

## Representative AIRS Mid-Trop CO<sub>2</sub> Averaging Kernels

### AIRS Sensitivity

- Peak sensitivity altitude varies slightly with latitude and season:
  - Tropics: 285 hPa
  - Poles: 425 hPa
- Width at half-maximum is ~ 400 hPa, spanning:
  - Tropics: 120 hPa to 515 hPa
  - Poles: 235 hPa to 640 hPa
- Tails of averaging kernels intrude into stratosphere, where air is older than in troposphere by an amount that varies with latitude  
 (~ 1 yr in tropics; ~5 yrs at poles).
  - Impact: 1-3 ppm near the poles.





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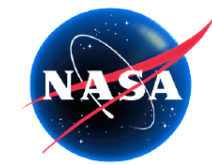
# Aircraft Profiles

## ✧ Direct validation of satellite retrievals

### ❖ Ideal characteristics:

- ✓ Spiral flight path
- ✓ Altitude range from near surface to 150 hPa (13.5 km)
- ✓ Coincide with the satellite overpass





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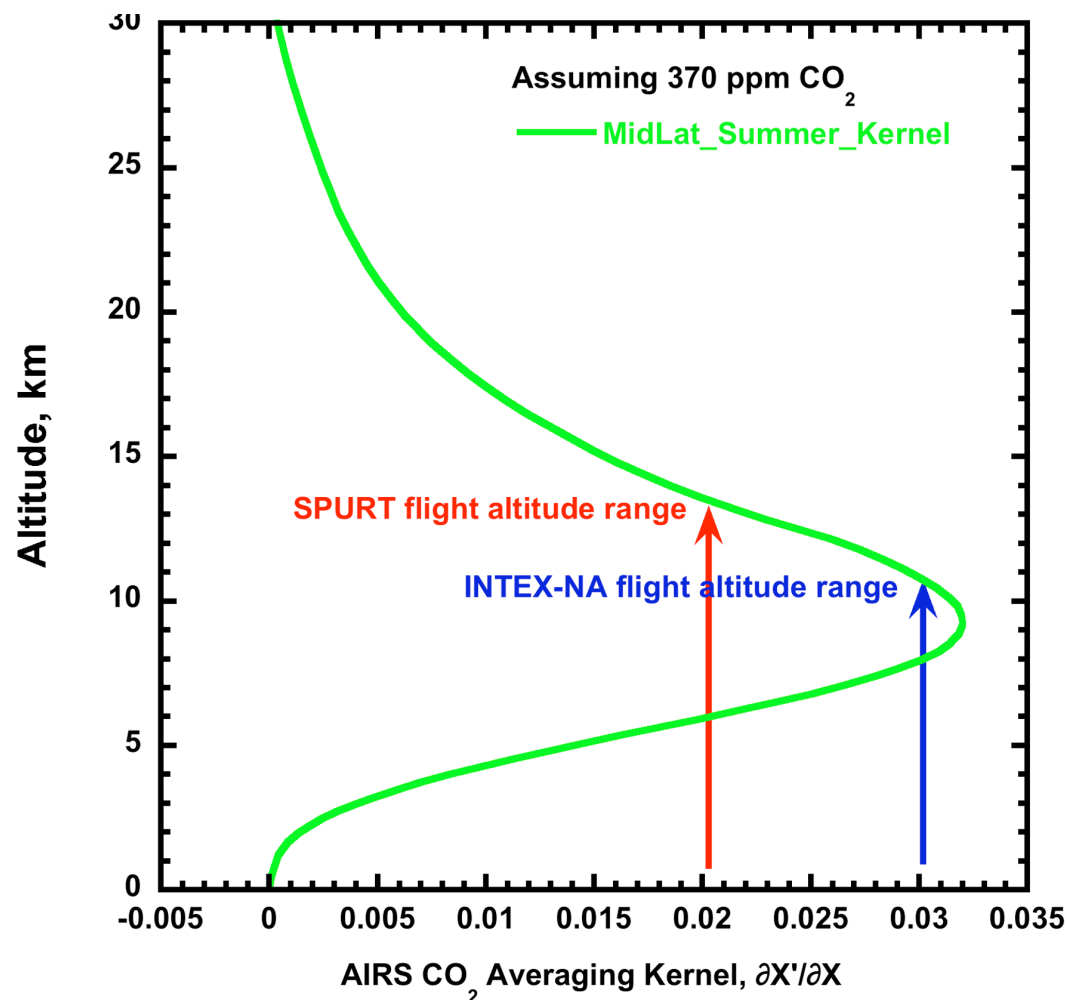
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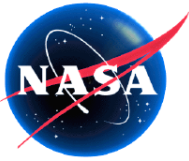
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## AIRS CO<sub>2</sub> Validation via Aircraft CO<sub>2</sub> Profiles

### Aircraft Profiles are Best Available Validation

- SPURT flights in April 2003:
  - Maximum Altitude: 13.7 km
  - Pressure Range: 800 to 140 hPa
- INTEX-NA flights in July 2004:
  - ~ 400 hPa, spanning:
    - Maximum Altitude: 10.7 km
    - Pressure Range: 800 to 240 hPa
- Convolve the aircraft profiles with the AIRS sensitivity functions to arrive at a single number to compare to the AIRS result. Extended the aircraft profiles to higher altitudes, assuming constant CO<sub>2</sub> concentration beyond highest altitude.
- Compared to average of same day AIRS retrievals within 500 km radius.





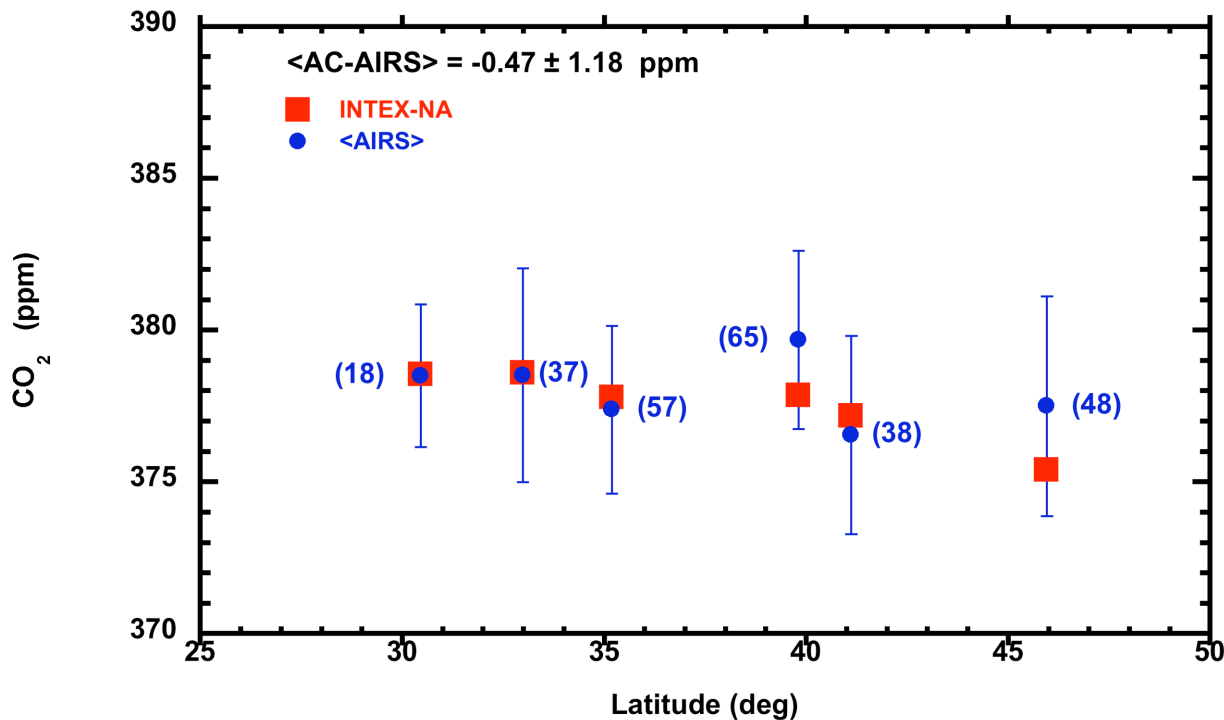
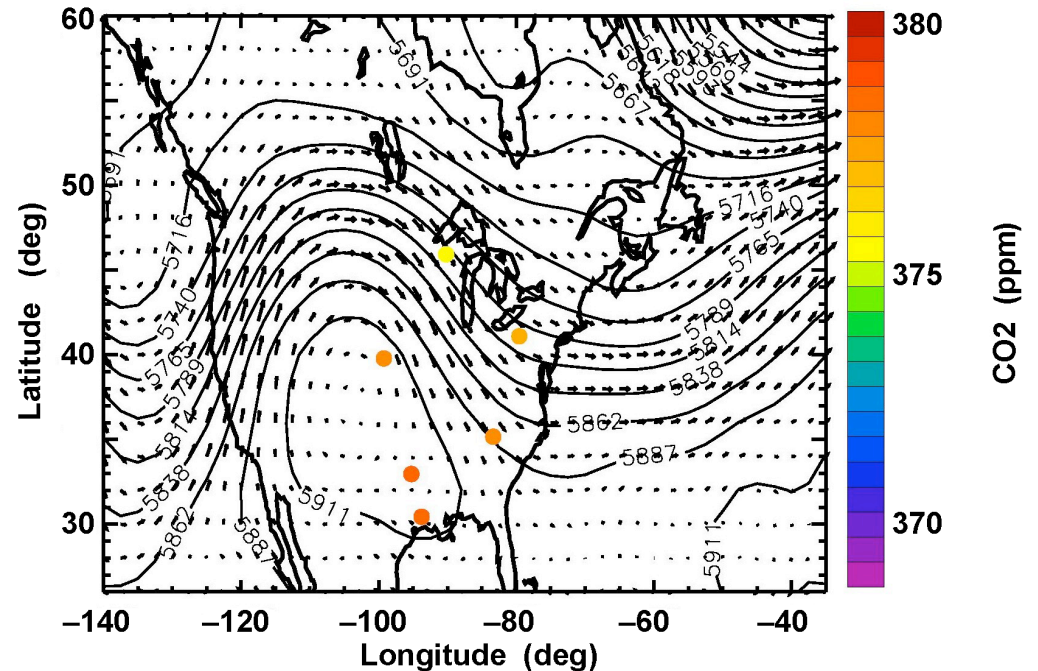
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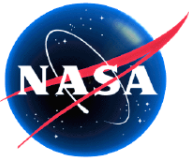
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Contours are NCEP 500 mb  
geopotential height.  
Arrows are NCEP 500 mb  
wind.

## Comparison of AIRS CO<sub>2</sub> Collocated with INTEX-NA Aircraft Data



Numbers in parentheses are  
number of same-day AIRS  
retrievals collocated within  
a radius of 500 km which are  
averaged for comparison to  
convolved aircraft profile.



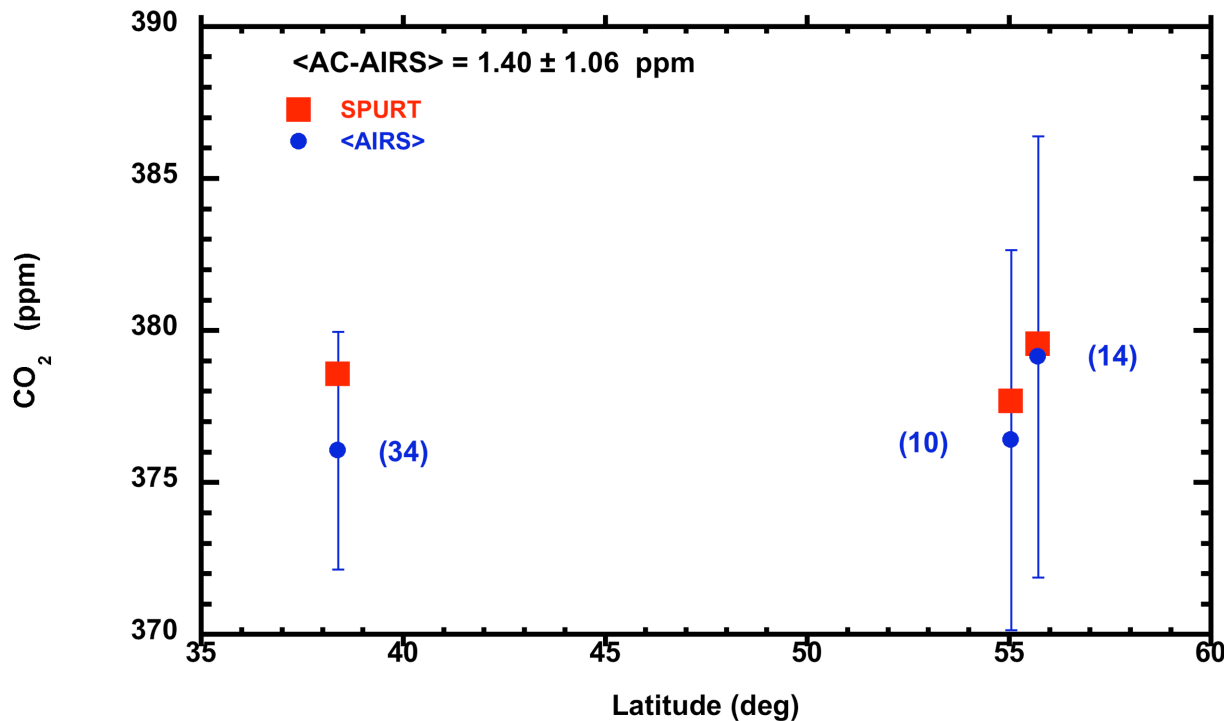
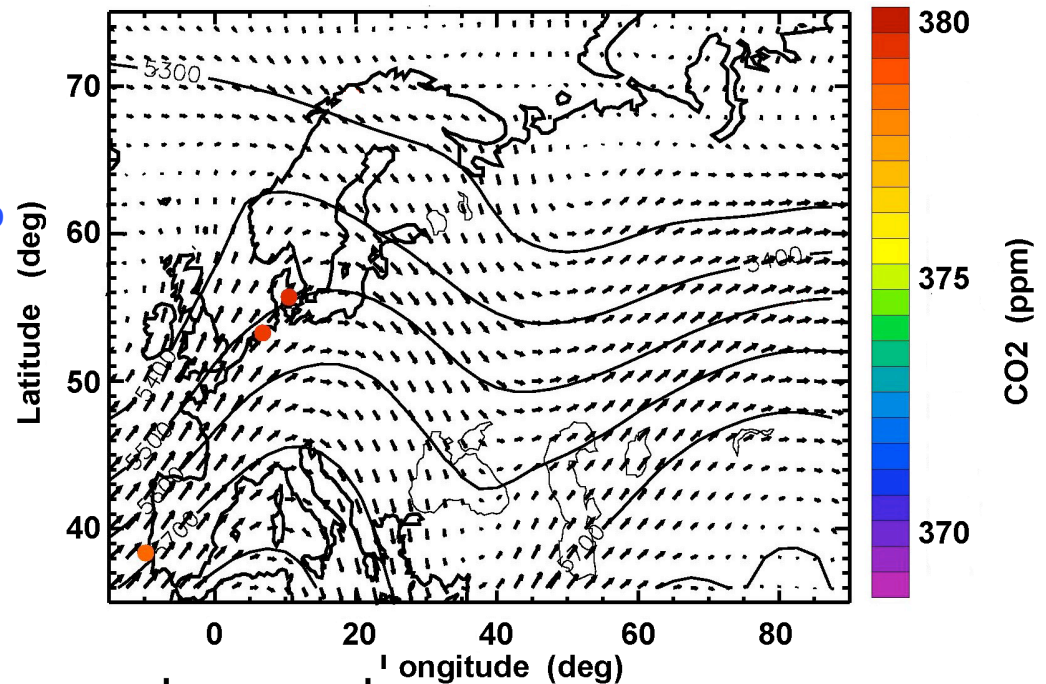
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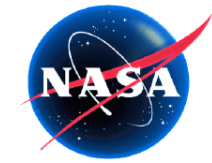
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Contours are NCEP 500 mb  
geopotential height.  
Arrows are NCEP 500 mb  
wind.

## Comparison of AIRS CO<sub>2</sub> Collocated with SPURT Aircraft Data



Numbers in parentheses are  
number of same-day AIRS  
retrievals collocated within  
a radius of 500 km which are  
averaged for comparison to  
convolved aircraft profile.



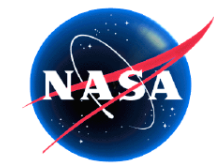
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## CONTRAIL CO<sub>2</sub> Samples at Altitudes Between 10.5 km and 12.5 km

- ✧ Provide a long-term history for  $30^{\circ}\text{S} \leq \text{latitude} \leq 30^{\circ}\text{N}$  over the Western Pacific Ocean at an altitude near that of the AIRS sensitivity maximum for the duration of the mission
- ❖ Validate:
  - ✓ Amplitude and phase of seasonal variations
  - ✓ Latitude-dependent interannual trend



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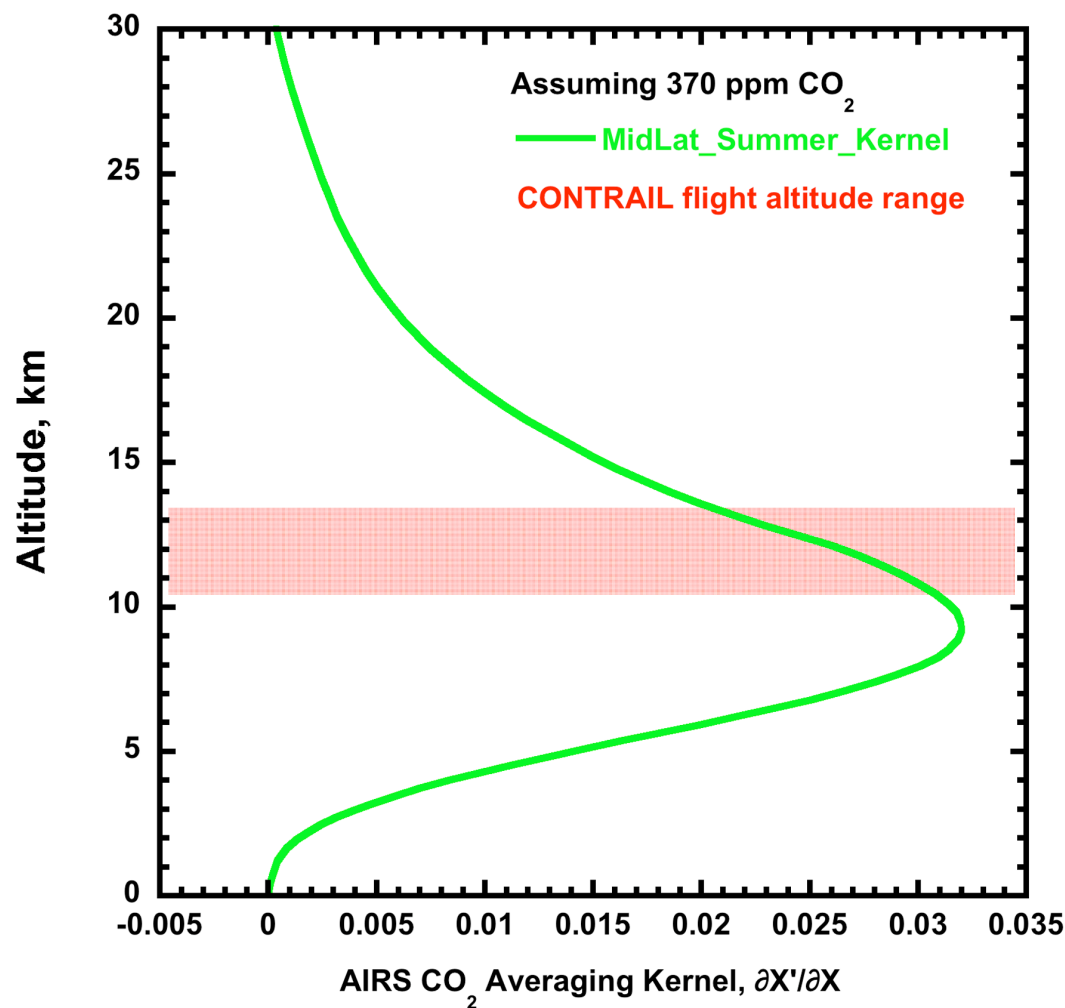
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## AIRS CO<sub>2</sub> Comparison to CONTRAIL CO<sub>2</sub> Measurements

CONTRAIL Measurements  
provide long timeline  
and wide latitude coverage

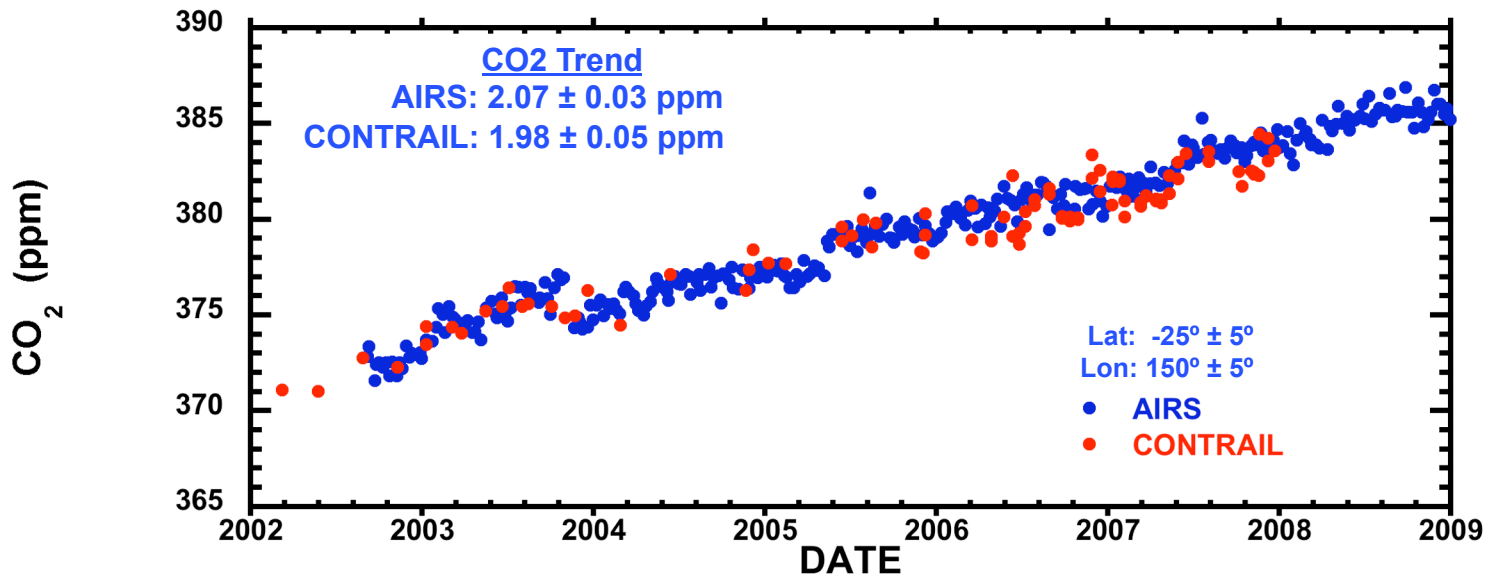
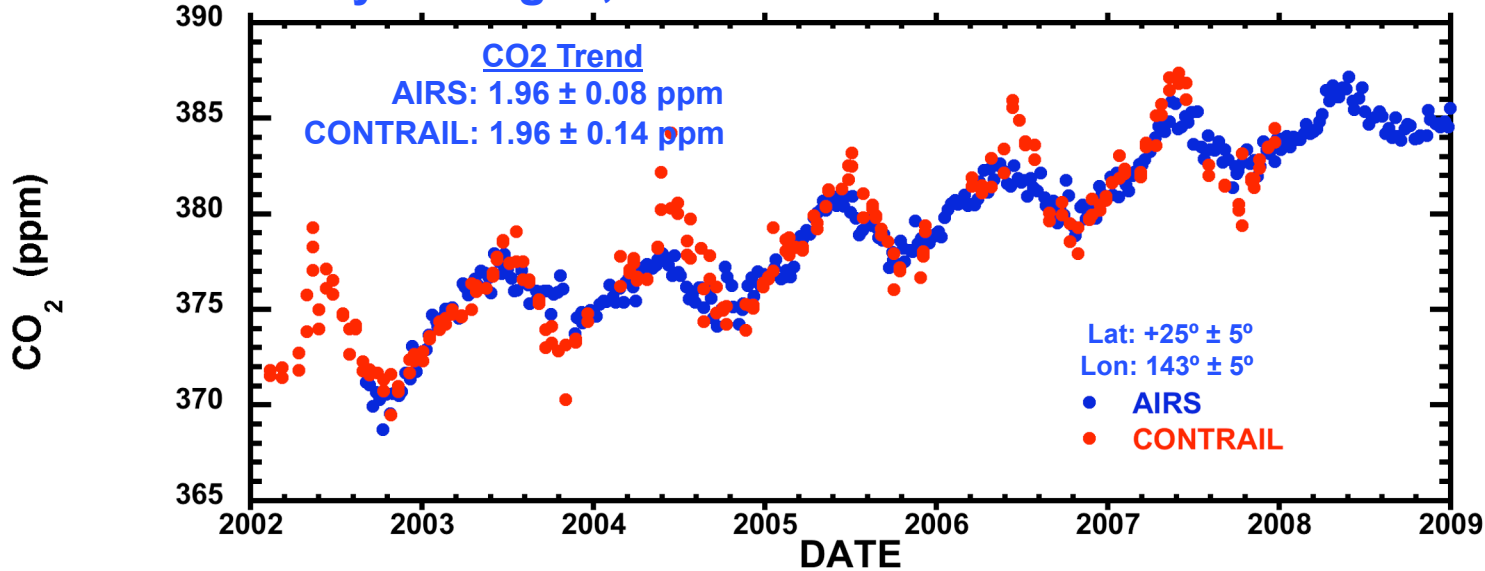
- CONTRAIL flights over ocean between Sidney and Tokyo:
  - Cruising Altitude: 10.5 – 12.5 km
  - Pressure Range: 240 to 180 hPa
  - Latitude Range: 30°S to 30°N
  - Longitude Range: 135°W to 153°W
  - Flight Periodicity: ~ twice/month
  - Sample Spacing: ~ 500 km
- Direct comparison of CONTRAIL flask samples with average of collocated AIRS retrievals.
- Collocated AIRS retrievals are within 250 km radius and 4 hrs of flight.



# Time Series for AIRS CO<sub>2</sub> and CONTRAIL Aircraft Data

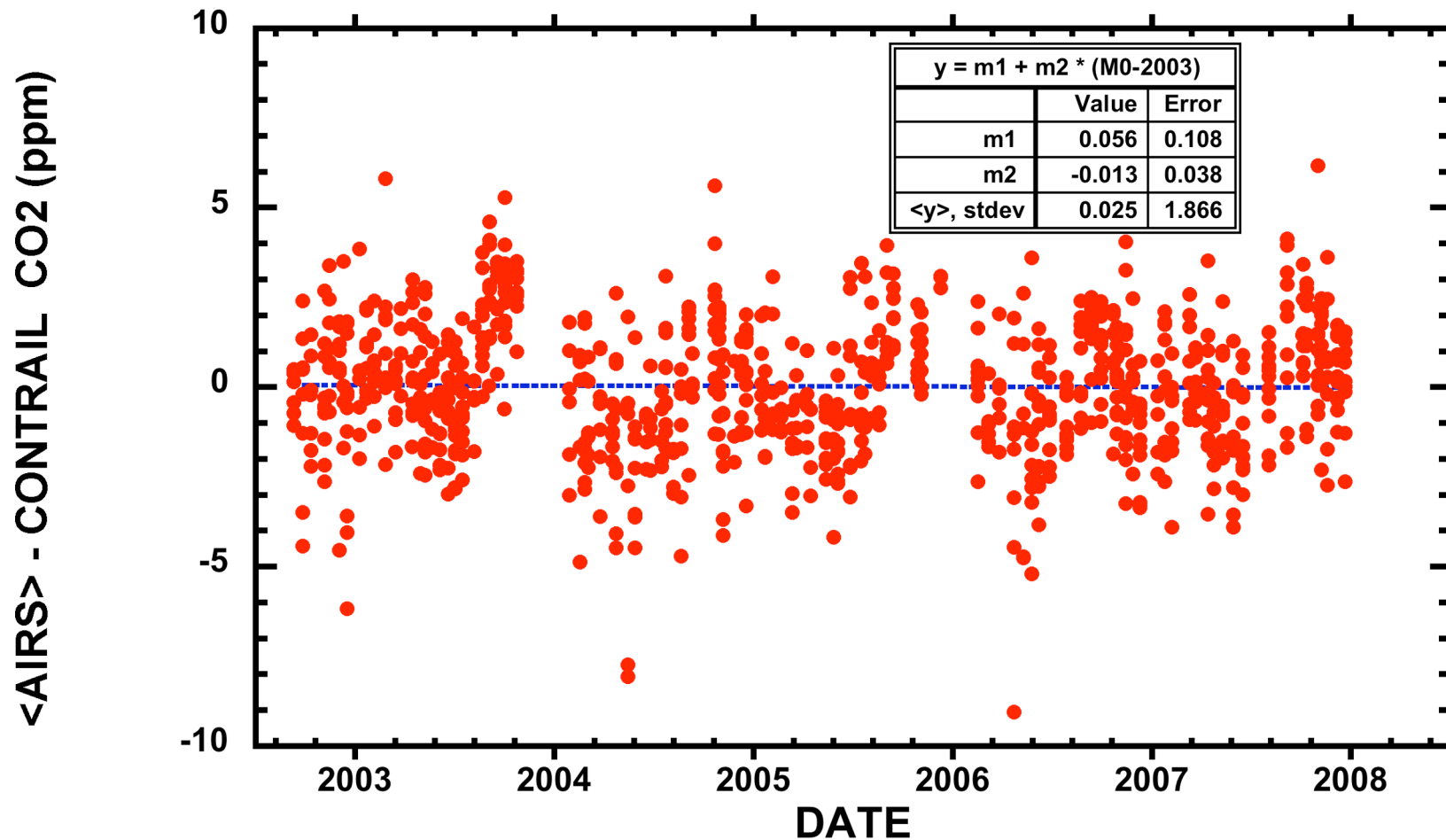
(in 10°x10° boxes at extremes of latitude for cruising altitude)

AIRS Data are 7-day averages; CONTRAIL data are individual measurements



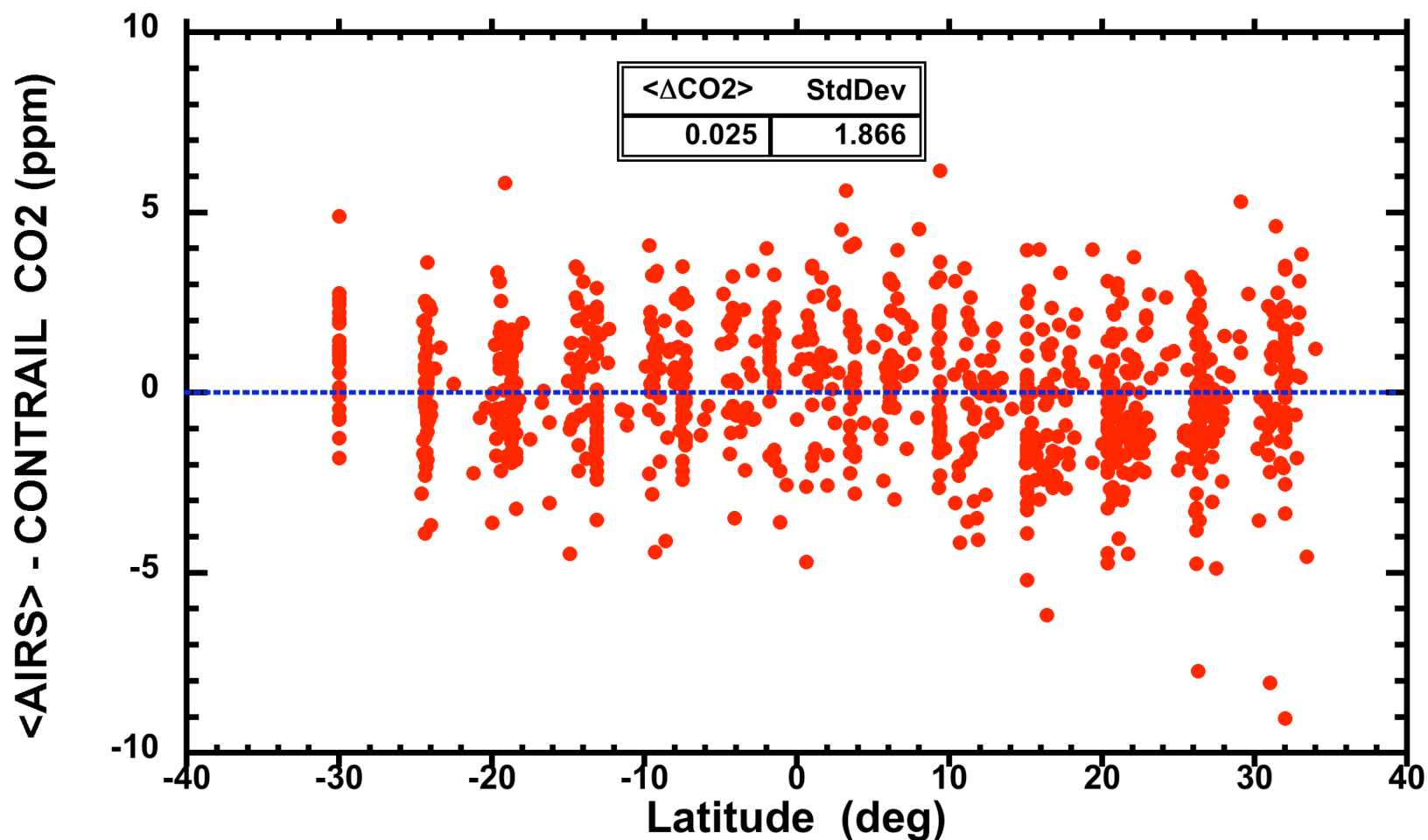
# Time Series for Difference of Collocated AIRS CO<sub>2</sub> and CONTRAIL Aircraft Data

(at least 3 AIRS retrievals collocated within 250 km radius & 4 hrs)



Over 5.25 years, bias ~ 0.2 ppm, stdev < 2 ppm and trend difference < 0.015 ppm/yr

## Difference Between Collocated AIRS CO<sub>2</sub> and CONTRAIL Aircraft Data as a Function of Latitude (at least 3 AIRS retrievals collocated within 250 km radius & 4 hrs)

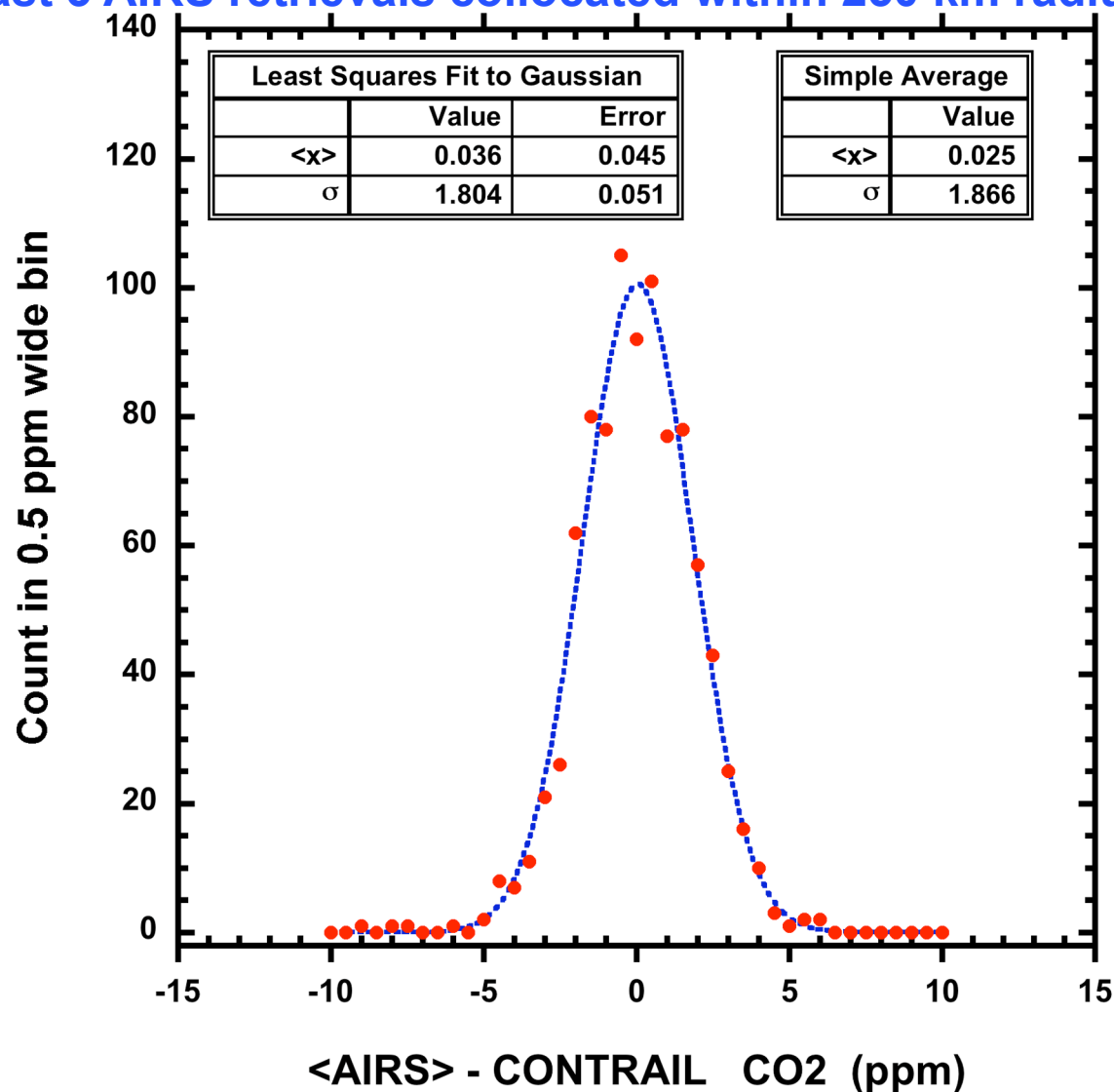


Over 5.25 years, bias  $\sim 0.03$  ppm, stdev  $< 2$  ppm and no apparent latitude dependence

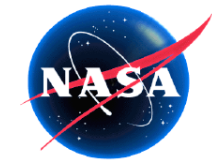


# PDF of Difference Between Collocated AIRS CO<sub>2</sub> and CONTRAIL Aircraft Data

(at least 3 AIRS retrievals collocated within 250 km radius & 4 hrs)



Over 5.25 years  
PDF is Gaussian  
bias ~ 0.04 ppm  
std dev < 2 ppm



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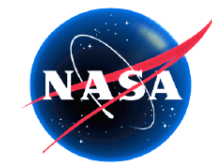
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# TCCON Daytime Cloud-Free Column Average CO<sub>2</sub> Measurements

✧ Provide a history of column average CO<sub>2</sub> at widely scattered locations around the globe

❖ **Validate:**

- ✓ Amplitude and phase of seasonal variations
- ✓ Interannual trend at select locations around globe
- ✓ Allow estimation of seasonal vegetative drawdown of CO<sub>2</sub> in PBL



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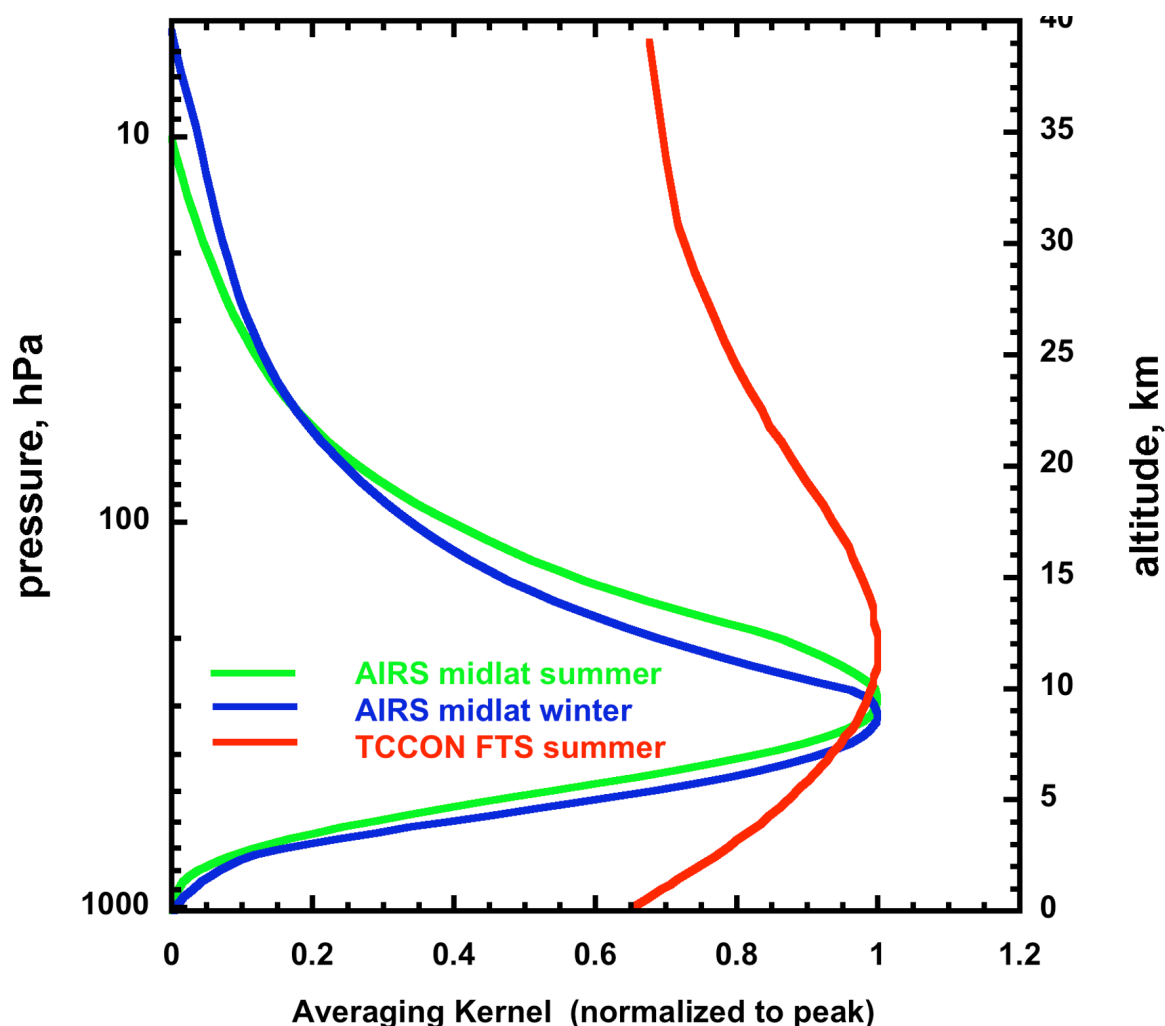
## Comparison of Averaging Kernels for AIRS Mid-Trop CO<sub>2</sub> and TCCON FTS

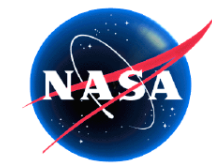
### AIRS Sensitivity

- Mid-latitude peak sensitivity altitude changes minimally with season:
  - Summer: 300 hPa
  - Winter: 330 hPa
- Width at half-maximum broadens slightly in winter, spanning:
  - Summer: 125 hPa to 515 hPa (390)
  - Winter: 150 hPa to 565 hPa (415)

### FTS Sensitivity

- Kernel is broad peak covering the full atmospheric column; excellent for determining the column average CO<sub>2</sub>
- In particular, high sensitivity in the PBL, the location of maximum CO<sub>2</sub> variability.
- Data are daytime, clear sky



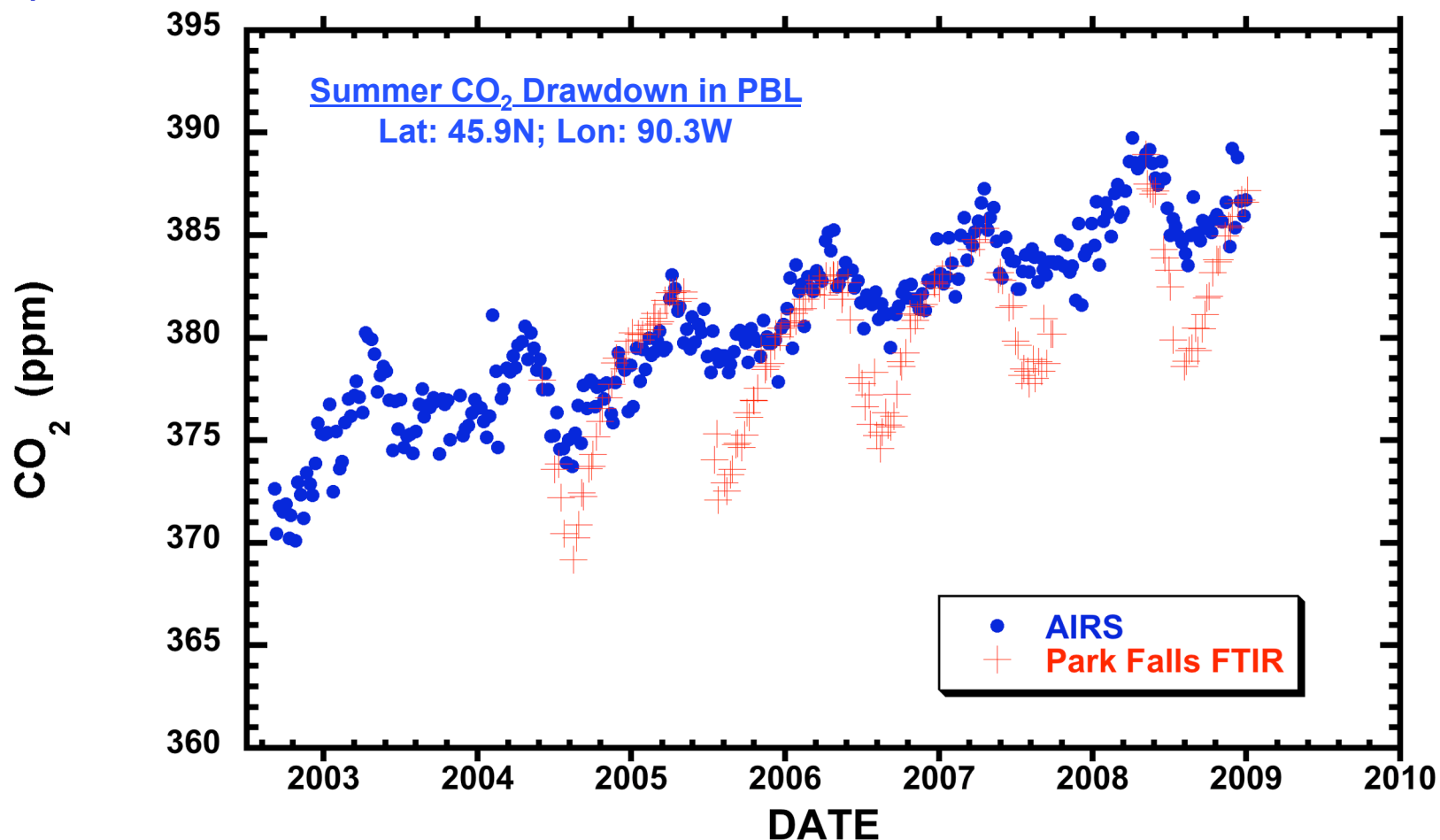


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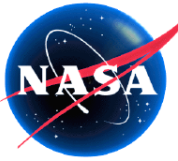
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## Comparison of 7-Day Averages of Collocated AIRS Mid-Trop CO<sub>2</sub> and Park Falls FTS



AIRS daytime data collated within radius of 500km of Park Falls  
Average of Selected Park Falls Pre-Release Data from Paul Wennberg & Gretchen Aleks

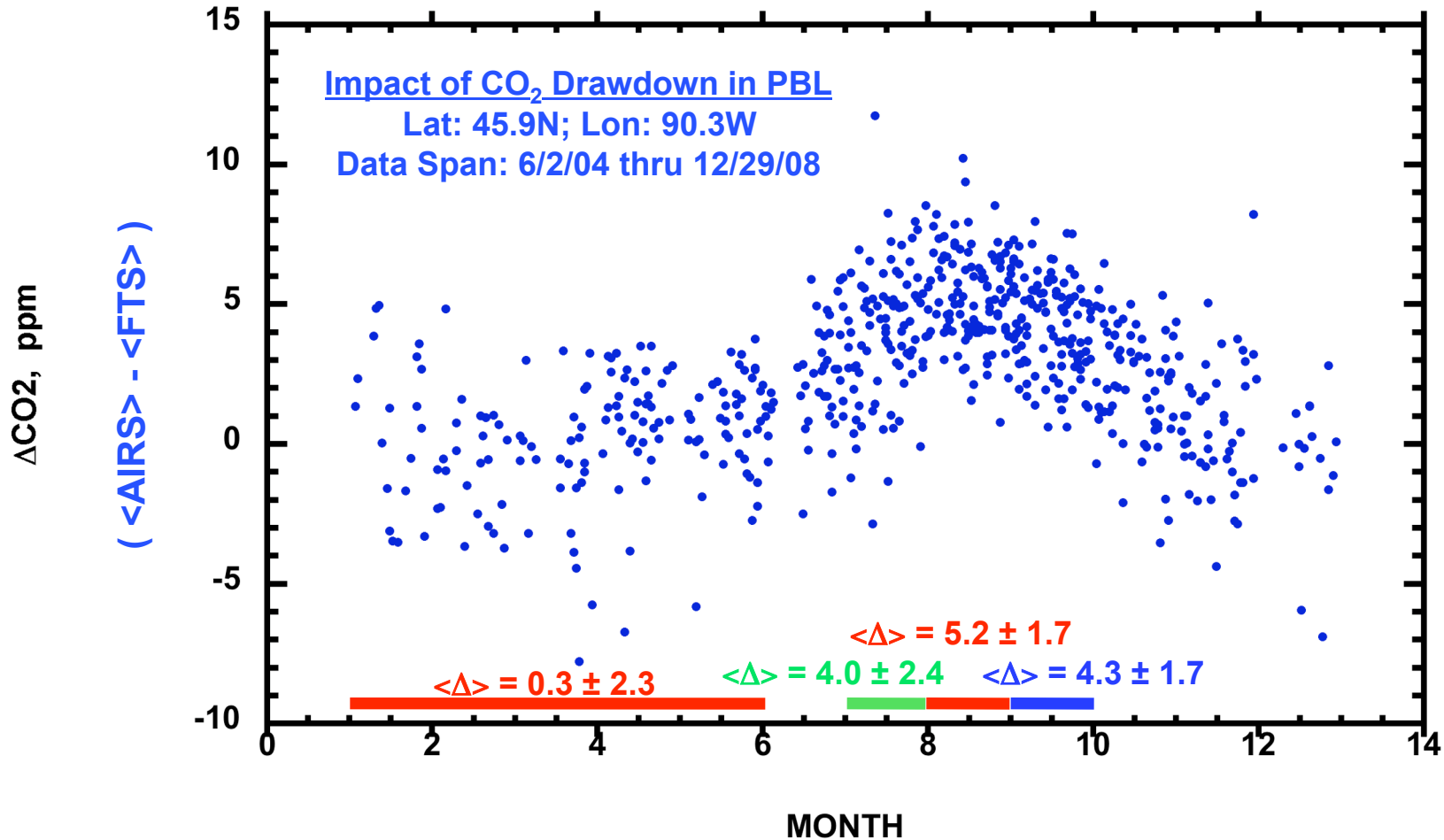


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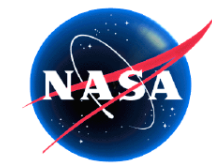
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## Comparison of Daily Averages of Collocated AIRS Mid-Trop CO<sub>2</sub> and Park Falls FTS



AIRS daytime data collated within radius of 500km of  
highest quality Park Falls data taken within  $\pm 2$  hours of AIRS overpass

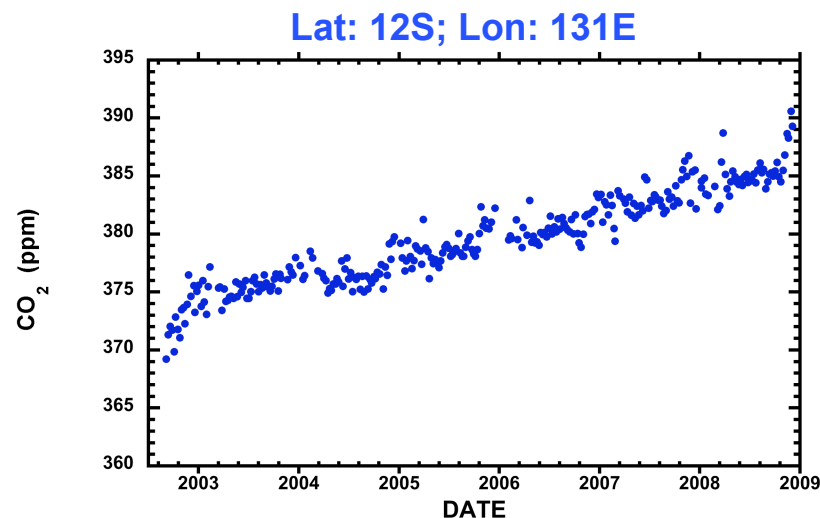
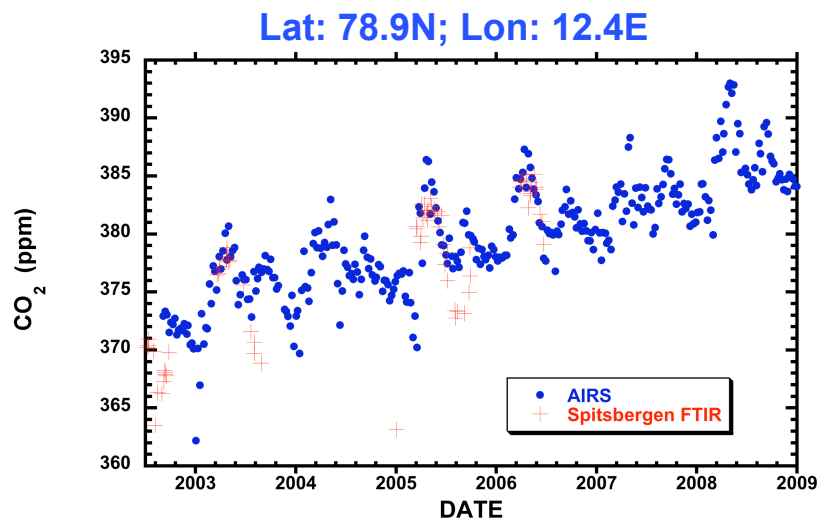
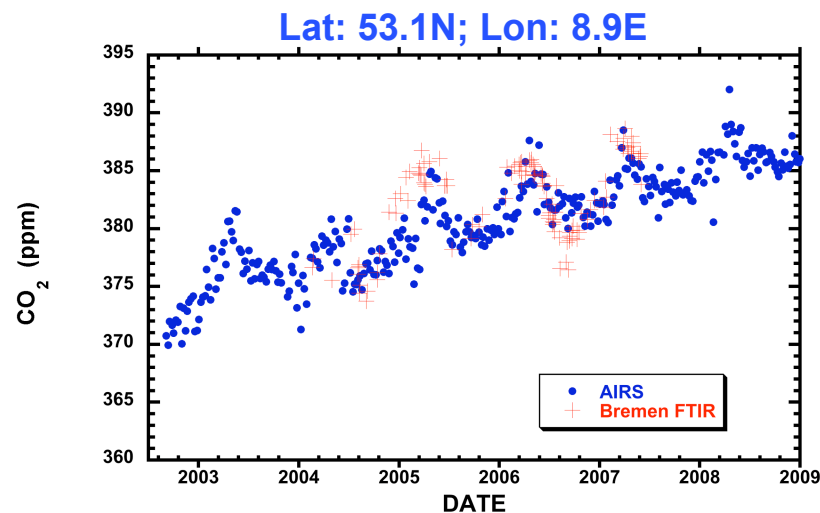
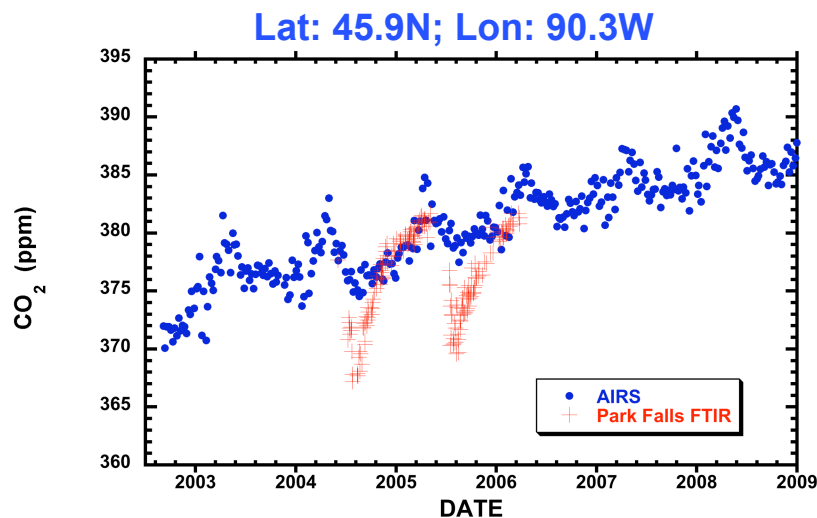


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# Comparison of 7-Day Averages of AIRS Mid-Trop CO<sub>2</sub> and Daily TCCON FTS

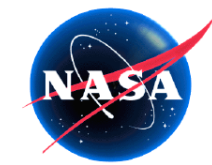


AIRS Data Collocated within radius of 250 km of FTS Sites

# Validation of AIRS CO2 Growth Trends

Time Series		<i>in situ</i> Rate/std ppm/yr	AIRS Rate/std ppm/yr	AIRS – <i>in situ</i> Rate ppm/yr
AIRS	60S-60N (1/03 – 12/08)		$2.02 \pm 0.08$	
CONTRAIL	30S-30N (1/02 – 12/07)	$2.01 \pm 0.04$	$1.98 \pm 0.05$	-0.03
CONTRAIL	25S $\pm 5^\circ$ (1/02 – 12/07)	$1.98 \pm 0.05$	$2.07 \pm 0.03$	+0.09
CONTRAIL	25N $\pm 5^\circ$ (1/02 – 12/07)	$1.96 \pm 0.14$	$1.96 \pm 0.08$	+0.00
Shemya	53N (1/02 – 12/07)	$1.97 \pm 0.40$	$2.03 \pm 0.11$	+0.06
Sand	28N (1/02 – 12/07)	$1.91 \pm 0.21$	$1.96 \pm 0.09$	+0.05
Ascension	8S (1/02 – 12/07)	$2.05 \pm 0.04$	$1.98 \pm 0.03$	-0.07
Mauna Loa	20S (1/02 – 12/08)	$1.94 \pm 0.12$	$1.95 \pm 0.01$	+0.01
Crozet	46S (6/02 – 12/07)	$1.95 \pm 0.03$	$2.17 \pm 0.05$	+0.22
Macquarie	54S (1/02 – 12/07)	$1.98 \pm 0.03$	$2.11 \pm 0.07$	+0.13

**Summary of growth rates per year and the differences  
between AIRS and several in situ measurements**

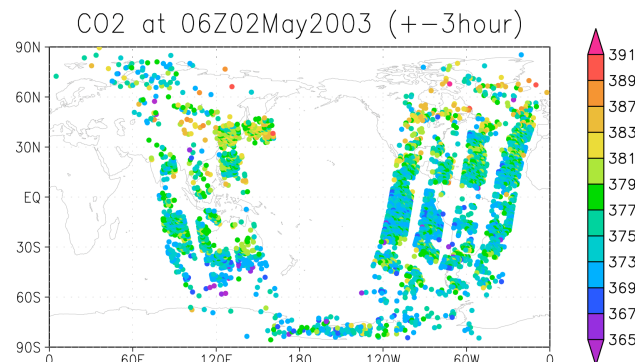
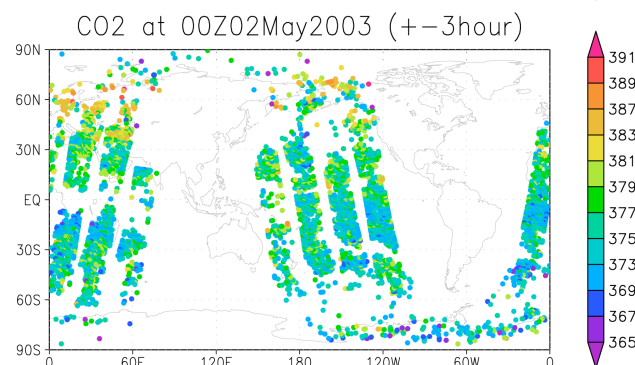
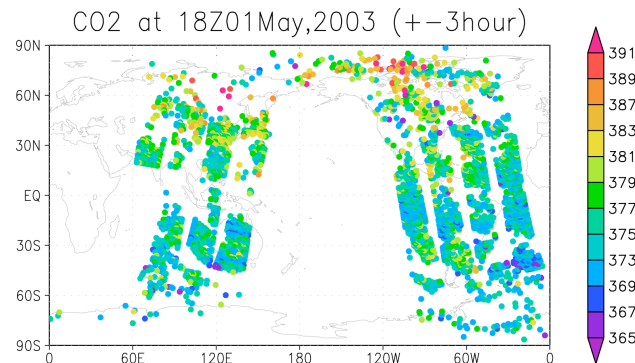
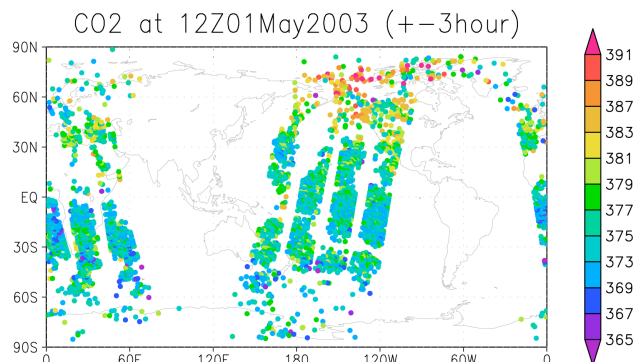
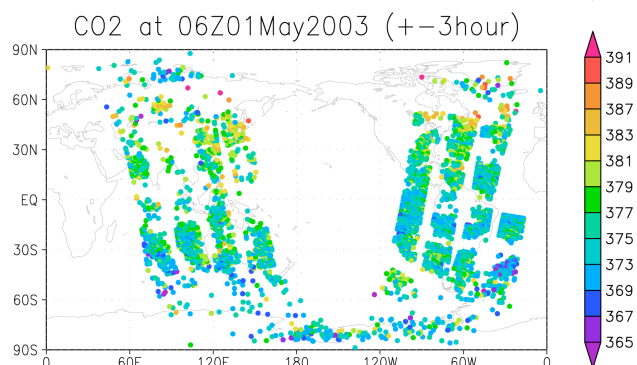
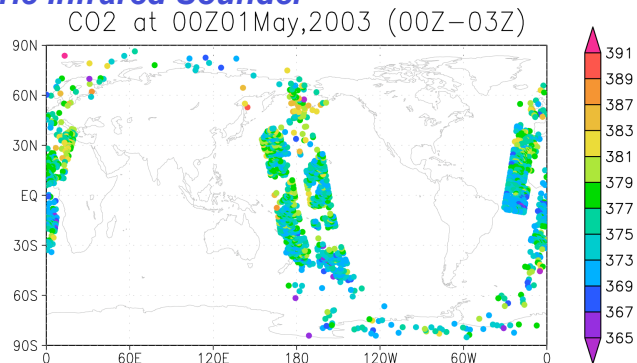


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# AIRS Individual Level 2 Mid-Trop CO<sub>2</sub> within 6-hour intervals



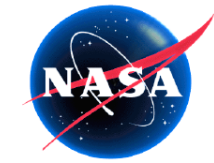
Eugenia Kalnay (UMCP), Junjie Le and Inez Fung (UC Berkeley)

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# Conclusions

- ✧ AIRS middle tropospheric CO<sub>2</sub> long term trends and seasonal variations are consistent with *in situ* measurements over different spatial, temporal scales from 30°S to 80°N with standard deviation better than 2 ppm
- ✧ AIRS CO<sub>2</sub> retrievals are valuable as a tracer to study concentration, distribution and transport of CO<sub>2</sub> in the free troposphere and validate coupling of the atmospheric physics and dynamics in chemistry transport models
- ✧ Need more high-quality *in situ* validation measurements
  - ✧ There are ~5,000 radiosonde launches/day
  - ✧ Desire 10% (500) CO<sub>2</sub> profiles/day around the globe
  - ✧ Require Southern Hemisphere expanded coverage



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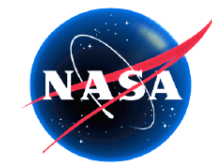
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## And Now For Something Completely Different, But Very...



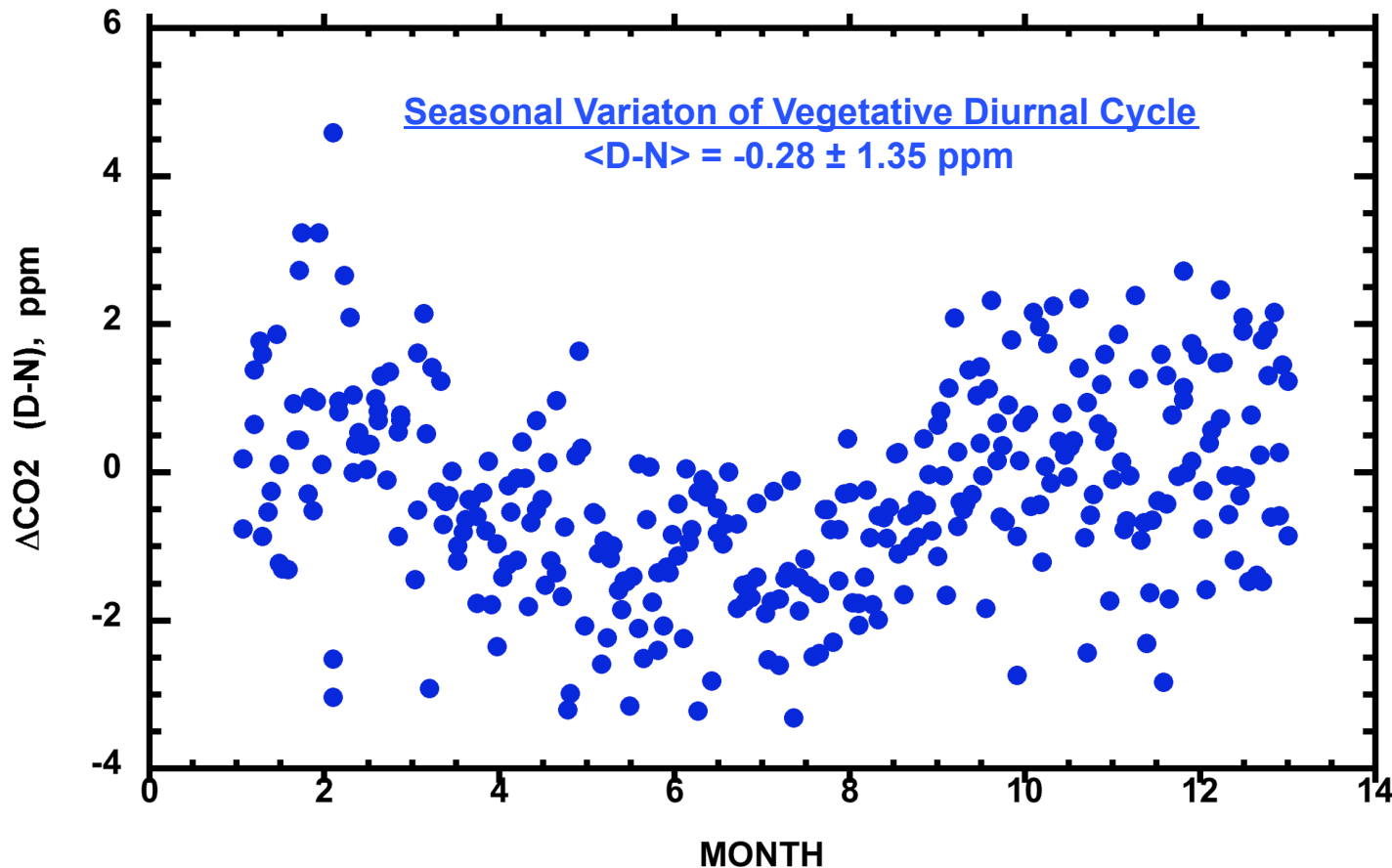
...interesting



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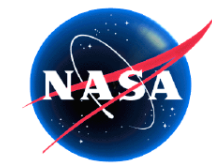
# Diurnal Variation of AIRS Mid-Trop CO<sub>2</sub> within 500km radius of Park Falls FTS

Lat: 45.9N; Lon: 90.3W  
Data Span: Sept 2002 thru Dec 2008



Monthly Average D-N $\pm$ std dev		
Jan	0.59	1.32
Feb	0.61	1.48
Mar	-0.45	1.15
Apr	-0.70	1.15
May	-1.43	0.80
Jun	-1.16	1.03
Jul	-1.38	0.91
Aug	-0.79	0.75
Sep	0.20	1.15
Oct	0.40	1.14
Nov	0.17	1.42
Dec	0.35	1.22

$\langle \text{AIRS 7-day daytime} \rangle - \langle \text{AIRS 7-day nighttime} \rangle$  within 500 km radius of Park Falls FTS



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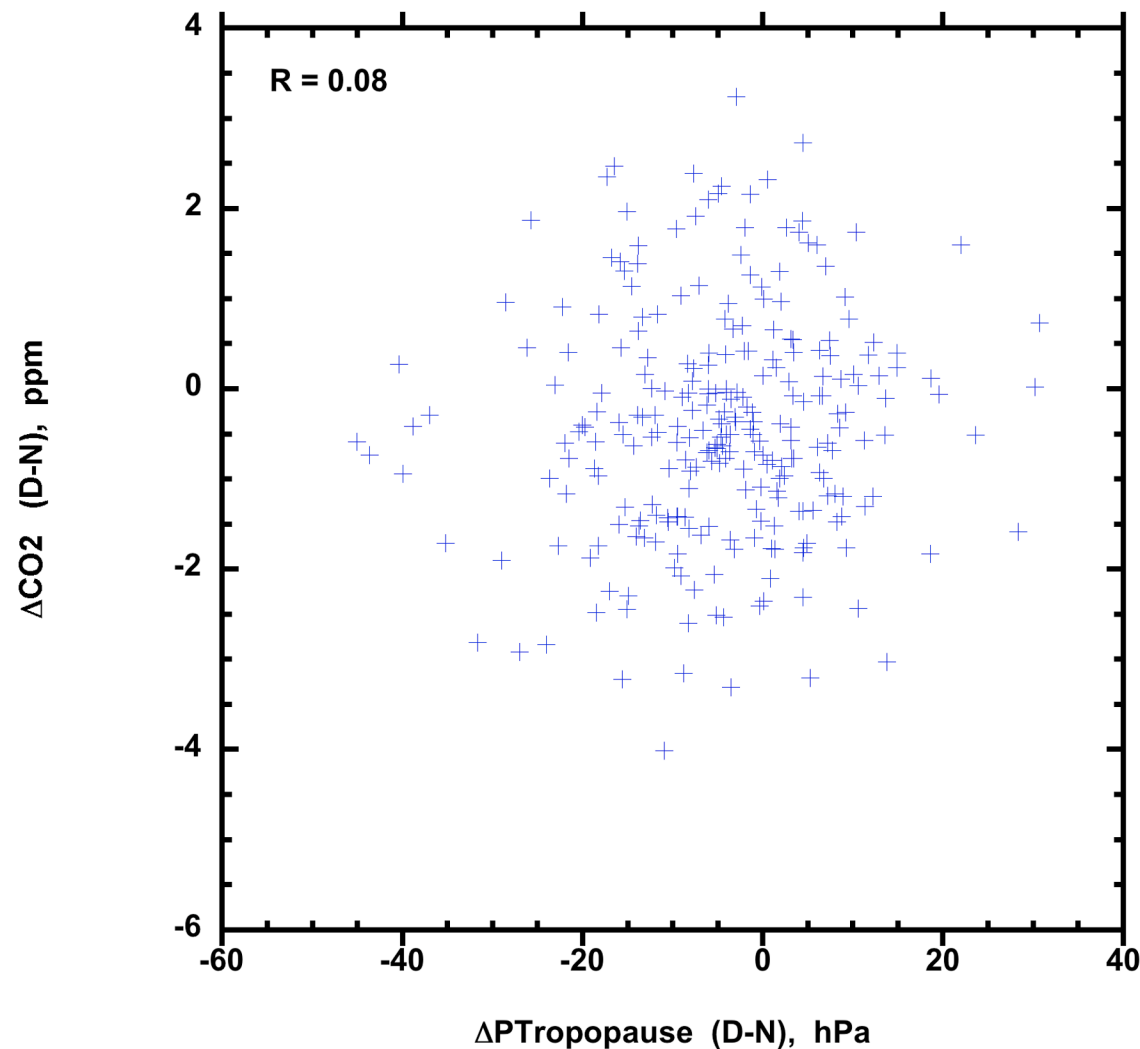
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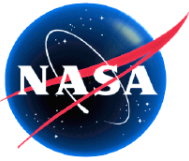
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Lat: 45.9N; Lon: 90.3W  
Sept 2002 thru Dec 2008

There is NO  
Correlation with  
PTropopause

## Diurnal Variation of AIRS Mid-Trop CO<sub>2</sub> within 500km radius of Park Falls FTS





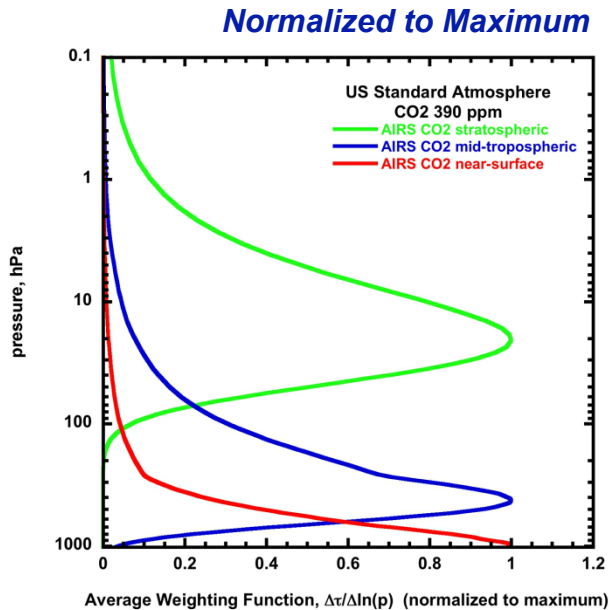
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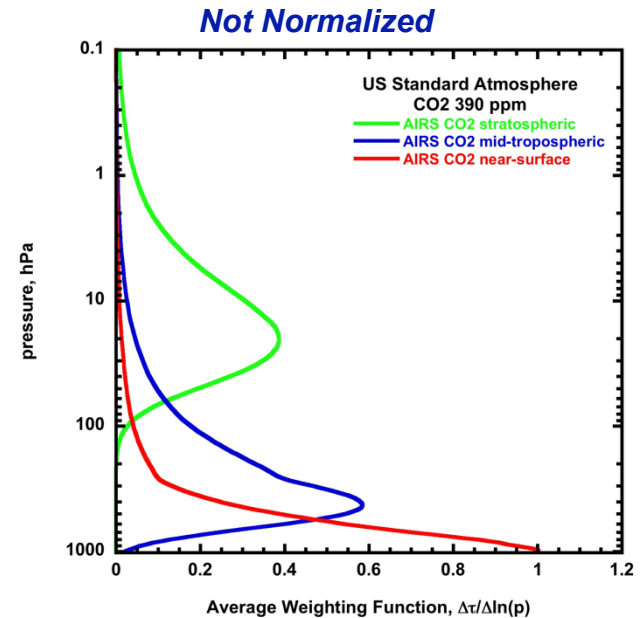
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# AIRS sensitivity for retrieving CO<sub>2</sub>

## AIRS can do it for three atmospheric levels



Global Hawk  
Peak Altitude  
(65,000 ft)



- Mid-troposphere (Completed)  
2002 to present  
Accuracy of 1 - 2 ppm
- Stratosphere (2009)
- Near-Surface (2010)